QUASI-PERIODIC OSCILLATIONS OF BLACK-HOLE CANDIDATES OBSERVED WITH BATSE

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ABSTRACT

We report here preliminary results of a study of the long-term temporal variability of three black-hole candidate (BHC) sources detected with the Burst and Transient Source Experiment (BATSE) onboard the Compton Gamma-Ray Observatory (CGRO). We detected peaked noise in several cases in the Power Density Spectrum (PDS) of the Fast Fourier Transform (FFT) in all these sources. The peaks are invariably in the range of 10 - 200 mHz. We present the evolution of the PDS during the outbursts of the two transient BHC (GRO J0422+32 and GX339-4) and a sample of the evolving PDS of the third source (Cyg X-1) over the 2.5 years of BATSE monitoring of this source.

1. INTRODUCTION

Aperiodic or quasi-periodic variability in the light curve of X-ray binary systems with a black-hole candidate (BHC) has been studied intermittently after its discovery in Cyg X-1 by Oda et al. in 1971. An extensive and comprehensive review of the subject has recently been given by Van der Klis (1994). We would like to add here that most of the reported analyses so far involved data from satellites covering the X-ray part of the electromagnetic spectrum (with the exception of the GRANAT spacecraft). BATSE offers the longest and most complete data base in γ-rays (25 - 300 keV) for all transients detected after April 1991, as well as a non-interrupted $\sim$2.5 year long record of the intensity variations of Cyg X-1.

Currently there are three sources detected with BATSE that exhibited aperiodic variability and evolving power spectra: Cyg X-1, GRO J0422+32 and GX339-4. We have used two data types in our study, that differ in time resolution. The background data (recorded with 1.024 s) are always available. In addition, Cyg X-1 and GRO J0422+32 were occasionally so intense, that they activated the onboard trigger and thus provided several high time resolution (0.064 s) data segments each $\sim$240 s long.

We have used the background model fit developed by B. Rubin et al. , 1992, to obtain residuals from the 1.024 s data; the model has 20 terms and provides a satisfactory fit to the slowly (due to atmospheric and diffuse background) and the rapidly (mainly due to strong sources) varying environment of the instrument. Transient events (γ-ray bursts, solar flares etc) are removed from the data prior to the fit. The "clean" data segments obtained this way range from several tens to hundreds of seconds, with the distribution peaking around 200 seconds. We therefore chose to analyse multiple 200 s long data strips.

2. OBSERVATIONS

2.1. Cyg X-1

Figure 1 shows a recent sample of the daily averages over 100 days (4/23/93 - 8/1/93) of the intensity of Cyg X-1 extracted with the occultation technique in the 45 - 140 keV energy range. We notice significant slow variation of the signal during this interval. The filled squares (1 through 5) indicate the periods over which we have calculated the Power Density Spectrum (PDS) of the source, usually 3 day averages between 20 and 300 keV. Figures 2a-e show the corresponding PDS. The spectrum evolves from practically flat over all frequencies (Fig. 2a) to a broad band noise spectrum with the break frequency set at $\sim$0.1 Hz (Fig. 2b) as the

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source signal decreases. At the source minimum the spectrum assumes an 1/f profile in both cases (Fig 2c and 2d), to return to the broad band noise type as the source signal increases again (Fig. 2e). The only indication of existense in the PDS of peaked noise comes during the decay (Fig. 2b) and rise (Fig. 2e) of the source signal, but is of low significance.

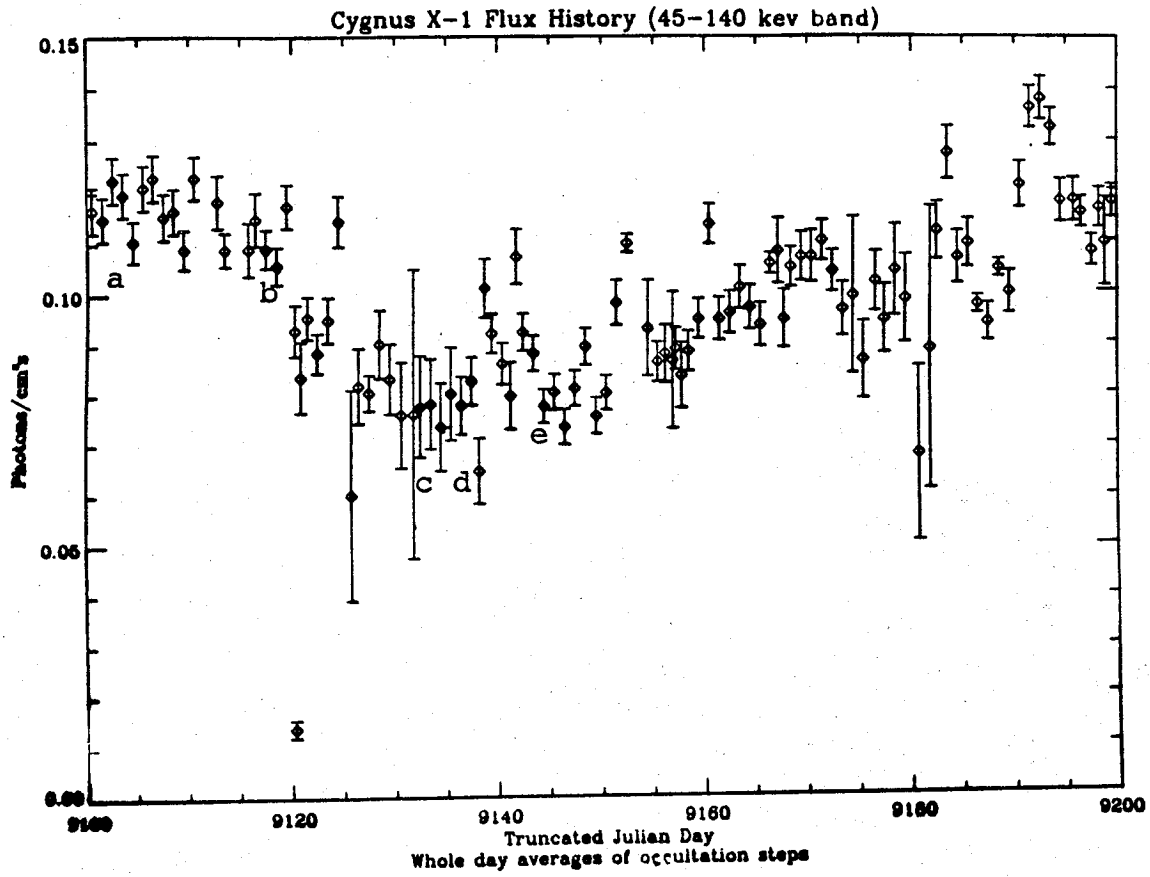

Figure 1. Cyg X-1 Flux history between 4/23/93 and 8/1/93 integrated over daily occultation steps between 45 and 140 keV. The letters a through e correspond to the PDS shown in Figure 2a-e.

Cyg X-1 went through a highly active phase, with intense fluctuations during the beginning of the mission (4/5/91 - 1/30/92) as seen in Figure 3. During this period BATSE triggered over 100 times either due to intense Cyg X-1 fluctuations or occultation steps. A typical 240 s trigger segment is shown in Figure 4. We analysed over ~30 triggered segments and found that in some cases the PDS shows a peaked noise with a centroid either around 70 mHz (Fig. 5a), or 40 mHz (Fig. 5b) or (in most cases) a power law spectrum, with no indication of peaked noise at all. Figure 3 indicates the part in the light curve where each type of PDS is detected. We see no obvious correlation between the appearance of the peaked noise and the source intensity.

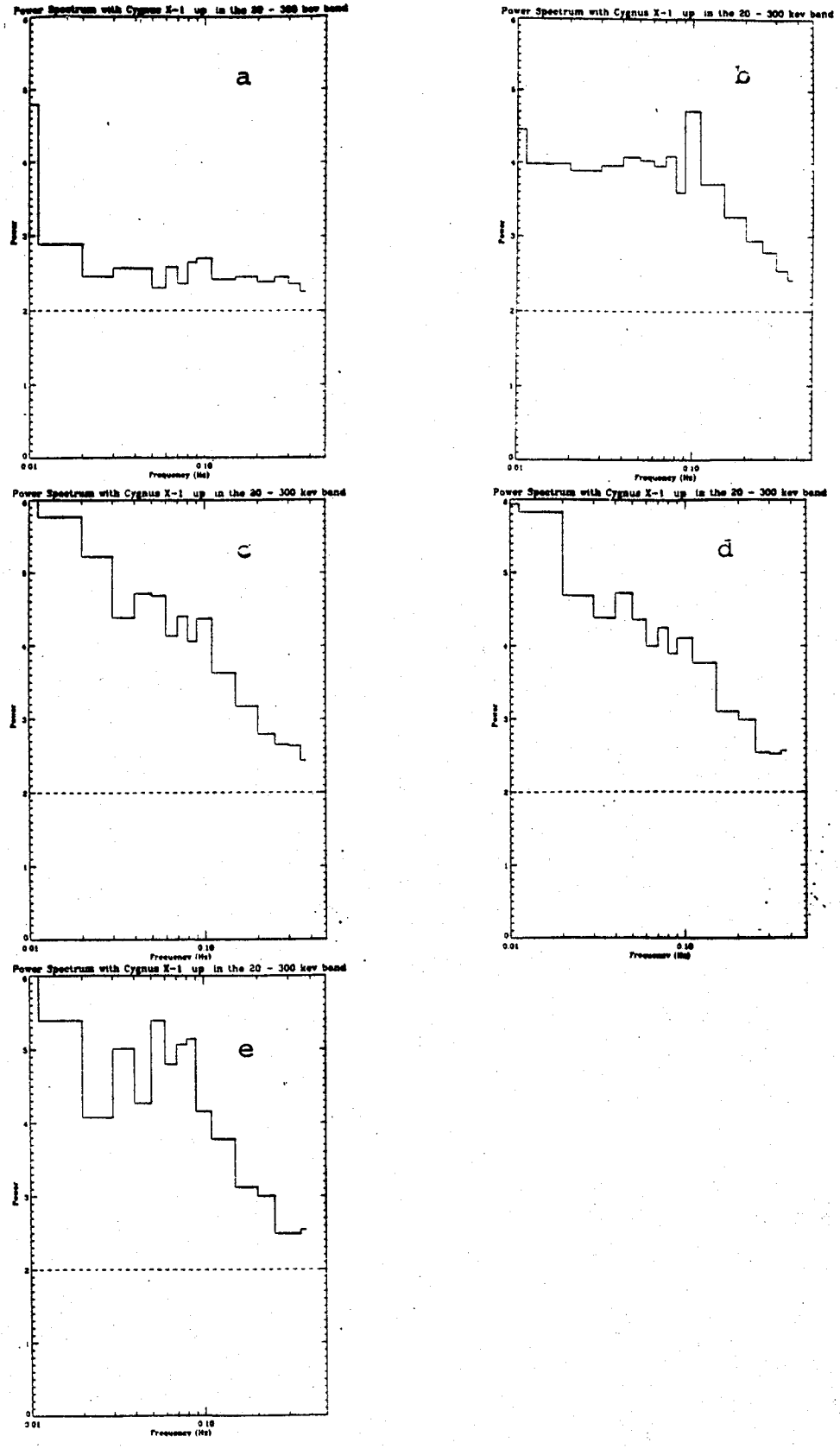

Figure 2. PDS taken as three day averages of the Cyg X-1 flux history as indicated by the letters a through e in Figure 1. The dotted line indicates the noise level of the spectrum normalised to a power of 2.

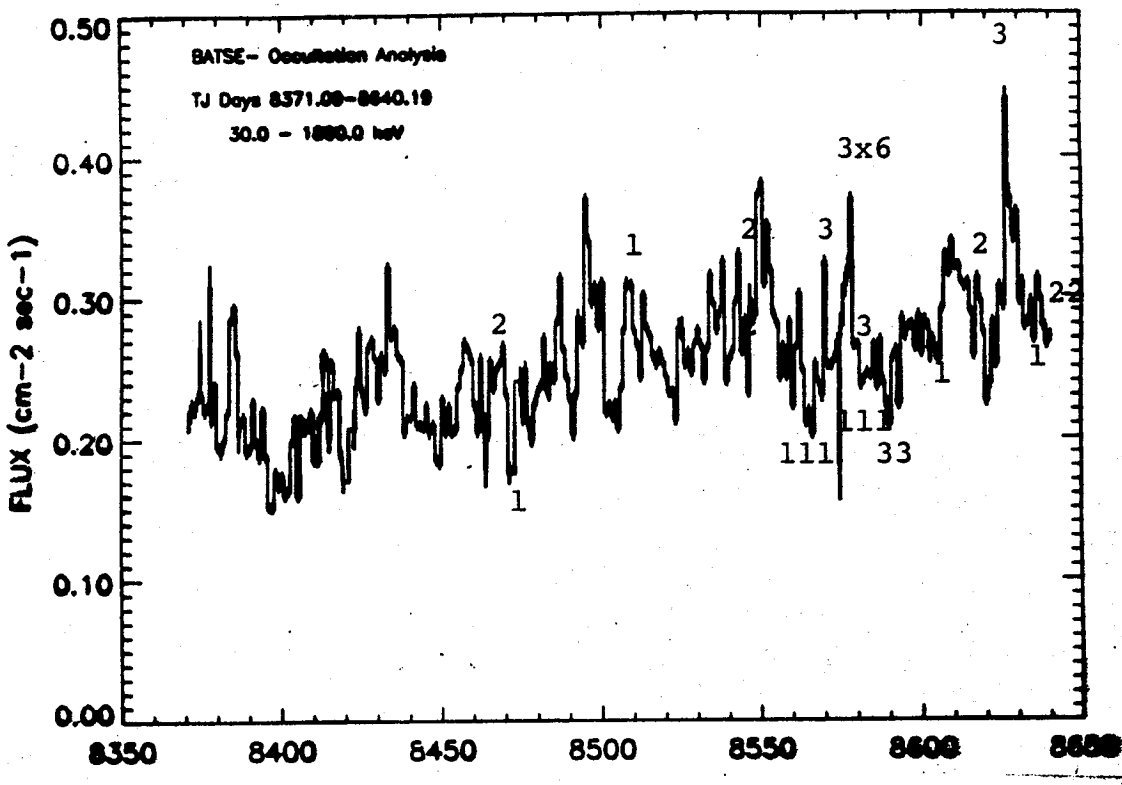

Figure 3. Cyg X-1 flux history during the beginning of the GRO mission (4/5/91 - 1/30/92). The numbers 1,2,3 indicate the results of the PDS: 1 marks PDS with evidence of peaked noise centered at 30-45 mHz, 2 marks PDS with evidence of peaked noise centered at 70 mHz and 3 marks days where the PDS show no evidence of peaked noise at all.

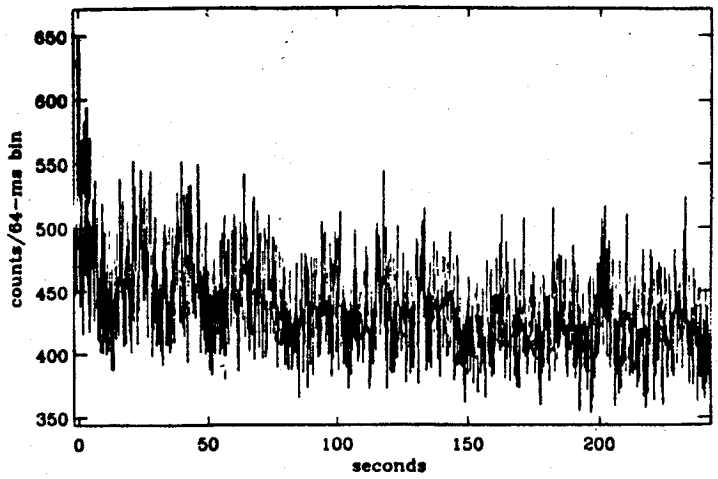

Figure 4. Typical time history of a Cyg X-1 trigger.

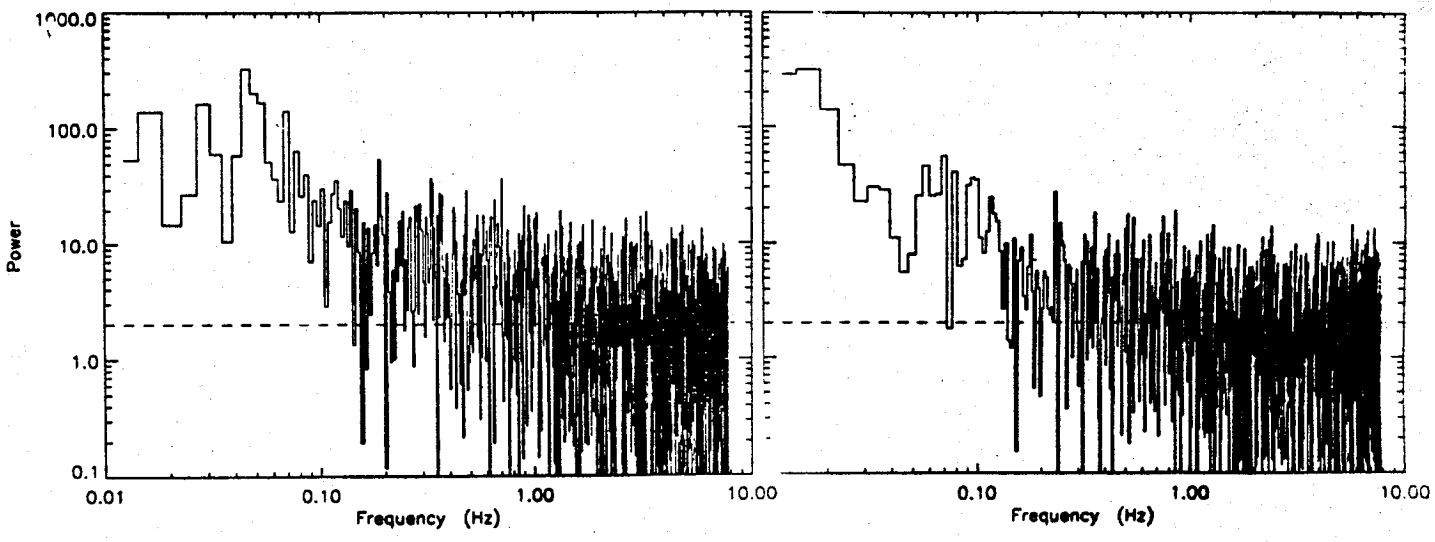

Figure 5. Characteristic PDS with peaked noise centered at 30-45 mHz and 70 mHz.

2.2. GRO J0422+32

GRO J0422+32 became active in August 1992. It reached a maximum around 8/15 and it also (during this time) resulted in several onboard triggers per day. We have shown in a previous paper (Kouveliotou et al. 1992) the PDS during a trigger and with 1.024 s data at the rising phase of the source. A narrow, quasi-periodic oscillation (QPO) peak is evident in both spectra, centered at 35 mHz. A secondary peaked noise feature is seen at 0.2 Hz. Figure 6 shows the flux history of the transient. Figure 7 shows a PDS taken at the peak of the transient outburst (M. Finger, private communication). Figure 8 shows the PDS of the second peak of the outburst (hatched area) superposed on a first peak PDS for comparison: the spectrum evolves from a power law at the maximum to flat at the secondary peak. No QPO evidence is found during the secondary maximum, but the analysis is still incomplete.

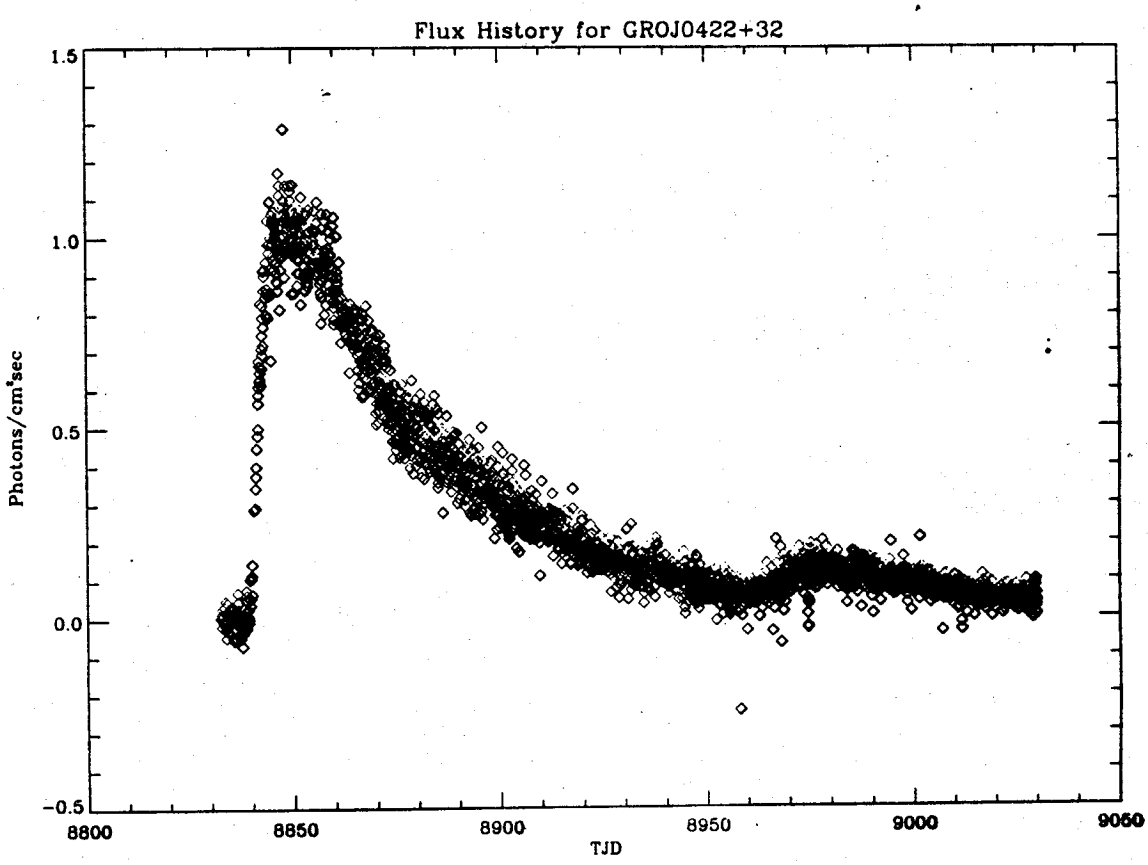

Figure 6. Flux history of the transient source GRO J0422+32.

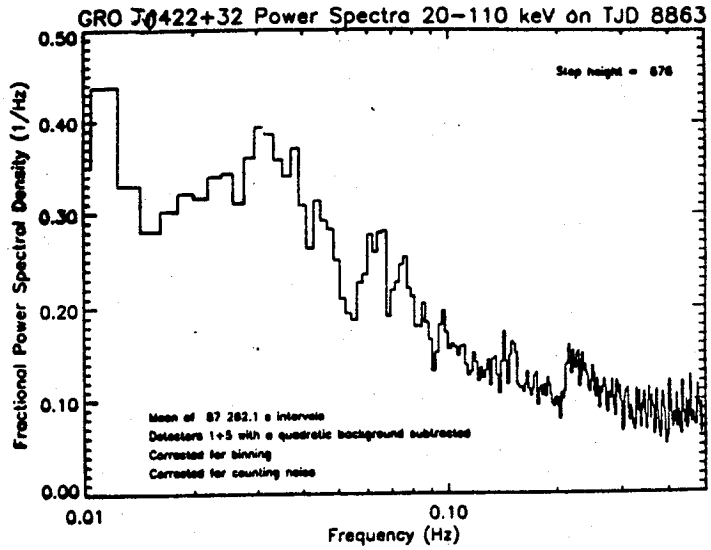

Figure 7. PDS of GRO J0422+32 taken at the peak of the outburst. Two peaked noise features are evident in the plot: one centered at 35 mHz and the other centered at 200 mHz.

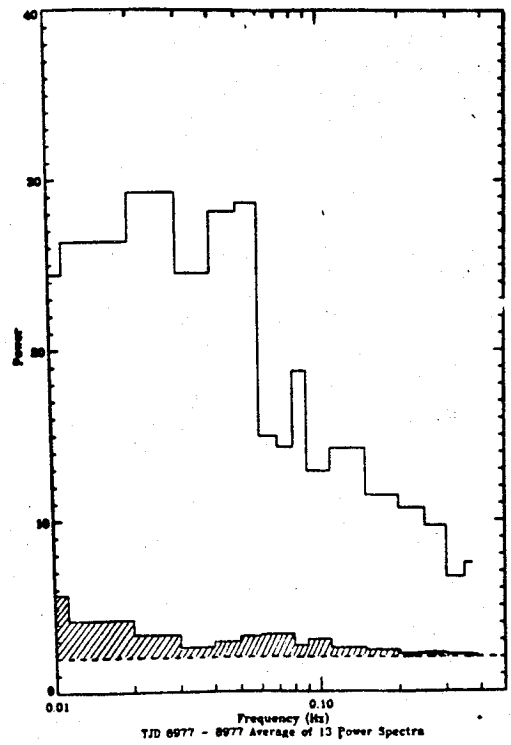

Figure 8. PDSs of the primary and secondary (hatched area) maximum of GRO J0422+32. Notice the reduction of the red noise level at the secondary maximum.

2.3. GX 339-4

GX339-4 was active once during 1991 and a second time at the end of 1992, beginning of 1993. The detailed time history of both outbursts is presented by Harmon et al. , in these proceedings. Figure 9 shows the QPO detected (Harmon, private communication) only during 2 days at the rising part of the 1991 outburst. The peak is narrow and centered at 26 mHz.

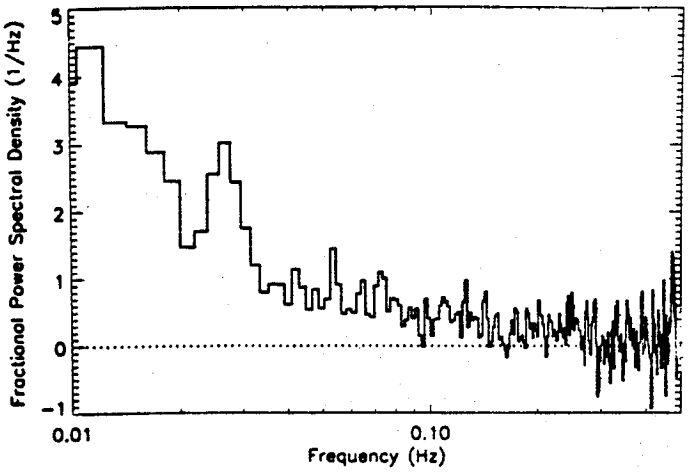

Figure 9. PDS of GX339-4. A QPO is clearly seen in the figure centered at 26 mHz.

3. CONCLUSIONS

We have presented preliminary results of the study of the intensity variations of three BHC sources. We find in all cases evidence for QPO or peaked noise centered at the 25 to 200 mHz range. This feature is not always present in the data and is not obviously related to other properties of the source (such as intensity or spectral hardness). When apparent, it is seen at energies between 25 and 150 keV. In the case of Cyg X-1 we have also observed PDS variations related to the overall intensity profile, as reported previously (Van der Klis, 1994 and references therein).

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